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REPORT NO. T15-88

THE PHYSIOLOGICAL DETERMINANTS OF LOAD BEARING PERFORMANCE AT DIFFERENT MARCH DISTANCES

U S ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE
Natick, Massachusetts

APRIL 1988

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4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Research Institute of Environmental Medicine 6b. OFFICE SYMBOL (If applicable) SGRD-UE-PH	7a. NAME OF MONITORING ORGANIZATION Same as 6a.
6c. ADDRESS (City, State, and ZIP Code)	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 6.2 / PROJECT NO. 3E162787A879 / TASK NO. 879B / WORK UNIT ACCESSION NO. 123

11. TITLE (Include Security Classification)

The physiological determinants of load bearing performance at different march distances.

12. PERSONAL AUTHOR(S)

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13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Technical Report	FROM Sep 86 TO Nov 86	April 1988	

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Load carriage, loaded marching physical performance, muscle strength, aerobic fitness,

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

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20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL

19. Abstract (continued)

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TECHNICAL REPORT

NO. T /88

The Physiological Determinants of Load Bearing Performance at Different March Distances

by

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April 1988

DISCLAIMER

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 on Use of Volunteers in Research.

The views, opinions, and/or findings contained in this report are those of the authors(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the expert technical assistance provided by the following individuals: Peter Frykman, Pamela Reich, SGT Ronald Manikowski, SSG John Hallmark, SGT Jose Castro, and SP4 Allen Vela from the U.S. Army Research Institute of Environmental Medicine. Special thanks are extended to Mr. Douglas Jones and Dr. Arthur Woodward of the Human Engineering Laboratory, Aberdeen, MD for the recruitment, housing, and logistical support of the test subjects. Sincere appreciation is expressed to Mrs. Dora Ward and Mrs. Emily Hamilton for the excellent preparation of this report. Finally, a special acknowledgement to the soldiers of the 7th Infantry Division, Fort Ord, CA without whose participation this study would not have been possible.

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ABSTRACT

The purpose of this study was to further our knowledge of the physiological determinants of load bearing performance over distances from 2 to 12 km. Twenty eight soldiers, experienced in load bearing, were initially assessed for: aerobic power ($\dot{V}O_2max$), leg strength and muscular endurance, maximal lift capacity, maximal heart rate (HRmax), body composition, body anthropometry, and submaximal treadmill response to load bearing. Following a week of fitness assessment, each soldier performed four, best effort, load bearing trials at distances of 2, 4, 8 and 12 km. All trials were scheduled in random order on four successive weeks. The total load carried (pack, weapon, and clothing) was 46.12 kg. Mean performance times for each distance were 16.0, 35.2, 77.2, and 125.0 minutes, respectively. Mean exercise intensity (% HRmax) as measured by HR telemetry for each trial was 74, 71, 69 and 63%, respectively. Correlation of fitness variables to performance times for the total group indicated no distinct physiological correlates at the shorter distances (2 and 4 km). However, at the longer distances (8 and 12 km), strength and endurance of the hamstrings and quadriceps muscles were significant predictors ($p < 0.05$) of load bearing ability. Subjects whose mean % HRmax was above the group mean displayed higher correlations for hamstrings and quadriceps strength and endurance at the three longest march distances. These results suggest strength and endurance of the lower body to be important considerations in heavy load bearing performance.

INTRODUCTION

Infantry troops are often required to carry heavy loads (45 kg or more) for long distances in order to accomplish assigned missions. Military objectives must be reached as quickly as possible, yet the effectiveness of the combat soldier must not be compromised. Therefore the ability to train troops to carry heavy loads is an important military concern for combat operations. The technological advances in modern weaponry have done little to decrease the burden of the combat soldier's load. Instead, as newer and more effective weapons have been developed, the total load of the modern day infantryman has increased rather than decreased. As such, today's combat soldier is forced to perform the dual role of fighting machine and beast of burden (3,5,14). Little is known, however, as to which physiological or anthropometric factors are important in heavy load bearing, and how best to train and prepare soldiers for this task.

Previous studies have documented the metabolic costs of load bearing as regards speed, distance, and terrain conditions (1,9,10,20,26). Recent work from this laboratory has suggested the contribution of upper and lower body strength components to load bearing performance (7,13). Dziados (7) tested 49 infantrymen carrying 18 kg for a distance of 10 miles, and found hamstring muscle strength to be the most significant predictor of prolonged load bearing performance. Kraemer (13) examined the effect of different training regimens on short duration, high intensity, load bearing and found that a combination of running and resistance training best improved load bearing capacity. A major difference between the two studies was the load bearing distance (10 vs 2 miles). It is possible that load bearing ability at shorter distances may require different physiological factors when compared to longer distances. It was, therefore, the purpose of this study to further identify the specific physiological factors which determine heavy load bearing performance over a range of march distances (2, 4, 8, and 12 km).

METHODS

Subjects were 28 active duty soldiers comprising a single rifle platoon from the 7th Infantry Division, Fort Ord, California. All subjects were fully briefed regarding the purpose and nature of the study and their informed consent was obtained prior to participation. For logistical purposes, the platoon operated in its usual formation of 4 squads of seven men each. During an initial week of baseline data collection, a fitness profile was obtained on each subject which consisted of: treadmill maximal oxygen uptake, body fat percentage, leg strength (hamstrings and quadriceps muscles), maximal lift capacity, and heart rate and oxygen uptake at three different submaximal walking rates (3.6, 4.8 and 6.0 km/hr).

Maximal oxygen uptake ($\dot{V}O_2max$) was assessed using a progressive, discontinuous protocol on a motor driven treadmill (4,17). Subjects initially ran at 9.7 km/hr and 0% grade for 6 minutes. Heart rate recorded from this exercise intensity then determined the running speed for the remainder of the test. Three to four additional runs of 3 minutes each were performed, separated by five minute rest periods. All runs were progressively increased in exercise intensity by raising the grade of the treadmill for each successive bout. Oxygen consumption was calculated from two 30 second samples of expired air collected in Douglas bags through a Koegel low resistance breathing valve during the final minute at each intensity. A plateau in oxygen consumption, defined as less than a $2ml \bullet kg^{-1} \bullet min^{-1}$ increase of oxygen uptake with a 2% increase in grade (16), was considered indicative of achieving $\dot{V}O_2$max. Gas volumes were measured with a Collins 120 liter chain-compensated spirometer. Expired air aliquots were analyzed for oxygen and carbon dioxide fractions with an Ametek model S-3A fuel cell and a Beckman model LB-2 infrared analyzer, respectively.

In order to estimate energy expenditure during marching, heart rate and oxygen consumption were determined for each subject on a Quinton model 18-60 motorized treadmill at three different walking velocities (3.6, 4.8 and 6.0 km/hr). Subjects carried the same load as in the performance marches (46kg), and the test comprised a 15 minute continuous walk in battle dress uniform (BDU) through all three work levels. Duplicate 30 second Douglas bag collections and heart rate determinations by modified V_5 electrocardiographic recordings were taken at the sixth, tenth, and fourteenth minutes of exercise. Gas analysis and ventilatory volumes were determined by the methods previously described.

Maximal lift capacity was determined by an incremental dynamic lift (IDL) test (15). All subjects began by lifting the 40 lb carriage of the lift device to a height of 72 inches. The carriage load was then incremented by 10 lbs each time until the subject could not lift the weight to 72 inches. The greatest weight successfully lifted was then recorded as the final score. The maximum weight capacity of the IDL was 200 lbs (90.9 kg).

Body composition was determined by underwater weighing. Subjects were clothed in a swimsuit, seated in an aluminum chair, and suspended in a 4 ft long, 4 ft wide, 5 ft deep aluminum tank filled with water maintained at 37°C. Underwater body weights were determined after subjects submerged and forcibly exhaled maxmally to their residual lung volume. An Ametek model 6001-A strain gauge system from which the subject was suspended rapidly recorded underwater weight measurements. Output from the load cell was digitized by a Model 59313A A/D converter and was sampled by a Hewlett-Packard model 85A desk top computer which was programmed to calculate % fat from underwater weight as well as other body composition parameters. A minimum of six trials were performed by each subject in order to obtain a stable measure of body density using the method of Fitzgerald et. al (8).

The estimation of residual lung volume, necessary for the calculation of body composition, was determined using the method of Wilmore et. al (24). In this method the subject exhales to his residual volume and then breathes (7 breaths) a pure oxygen mixture for subsequent analysis of the diluted expired air. Several trials were taken and the mean of the two closest trials was used.

Dynamic strength of the knee extensors (quadriceps) and knee flexors (hamstrings) was measured with the Cybex II dynamometer as described by Caizzo et. al (2). For knee extension, subjects were seated in the Cybex chair with the dominant leg strapped to the lever arm of the dynamometer so that the machine's axis of rotation was in alignment with the subject's knee joint. The dynamometer held the velocity of contraction constant while measurements of torque and total work were obtained. On command, the subject extended his leg with maximal voluntary force completing about a 90° range of motion. Limb movement was isolated by means of straps across the chest, waist, and thighs. The subject performed 3 consecutive maximal contractions at angular velocities of 0, 30, and 180 degrees/second. From the average of three contractions at each angular velocity, peak torque was calculated.

For measurements of hamstring strength, the subject lay face down on a padded bench with the dominant leg attached to the lever arm of the dynamometer. Limb movement was isolated with straps across the back, thigh and buttocks. Vertical and horizontal body movement was restricted in order to ensure machine-subject alignment. Three maximal contractions were performed at angular velocities of 0, 30, and 180 degrees/second from which peak torque values were determined.

Lower extremity muscular endurance (hamstrings and quadriceps) was also measured with the Cybex II dynamometer as described by Thorstensson (21). Subjects were prepared in a manner identical to that for strength testing and were instructed to perform 50 consecutive maximal contractions at an angular velocity of 180 degrees/second. From these 50 contractions, mean torque and % peak torque decrement values were determined for both the hamstrings and quadriceps muscles.

Following the week of fitness assessment, each soldier performed in random order four load bearing trials at distances of 2, 4, 8, and 12 kilometers. The trials were carried out on four successive weeks with each distance traversed by one fourth of the total group on each test day. Each subject carried a total of 46 kg of which 28 kg were carried in an Alice pack with frame and 18 kg on the body (vest, helmet, weapon, etc). Each soldier was instructed to give his best individual effort in completing each distance in the fastest possible time. Daily temperatures during the load bearing trials ranged from 48-69^{O}F with an average of 59^{O}F. Relative humidity ranged from a low of 41% to a high of 95% with a daily average of 64%. Each of the four distances was traversed by each squad on successive Mondays over a four week period and performance times were recorded to the nearest tenth of a minute. Water was freely given during all marches and subjects were permitted to stop and rest for brief periods if they so chose but this was not subtracted from their elapsed times. Investigators were present in the field to monitor the progress of each trial and a physician was present during each march to observe the subjects and treat any injuries. All investigators were equipped with 2-way radios and were in constant contact with each other throughout the course of each load bearing trial. Heart rate was recorded by telemetry (Perceptronics, model BRS-1) and was monitored visually at the telemetry receiver during all load bearing trials.

In order to determine relative levels of exertion, heart rate recordings from the four march distances were used to estimate exercise intensity levels according to the method of Karvonen et al (12). In this procedure, a subject's mean heart rate for each load bearing trial was expressed as a percent of his maximal heart rate capacity according to the following equation.

$$\text{HR march} = (\text{HR max} - \text{HR rest})(\%\text{HR max}) + \text{HR rest}$$

This permitted investigators an objective means of estimating individual subject effort from continuous heart rate recordings.

An analysis of variance (ANOVA) was performed to identify intrasquad differences which might have occurred during performance of the various march distances. If the resultant F-tests showed significance, a Tukey's post-hoc test was performed. An alpha level of 0.05 was chosen to indicate statistical significance. Simple Pearson product-moment correlation coefficients were performed between mean march times and the physiological variables measured in this study.

RESULTS

Table 1 presents the physical characteristics of the 28 Infantrymen who participated in this study. The average fitness level ($\dot{V}O_2$max) of these soldiers was higher than comparable groups previously measured by this Laboratory (7,16,22,23). Table 2 presents leg strength and endurance data for subjects measured in this study. Dynamic strength of the knee extensors was considered a measure of strength of the quadriceps muscle group, while dynamic strength of the knee flexors was considered indicative of the strength of the hamstrings muscle group. Highest peak torque (PT), mean peak torque (MT), and % decrement in peak torque were also calculated.

TABLE 1. PHYSICAL CHARACTERISTICS OF SUBJECTS (n=28)

VARIABLE	MEAN (SD)	RANGE
Age(yrs)	21.7(3.3)	18.0 - 29.0
Height(cm)	173.5(5.8)	163.3 - 183.2
Weight(kg)	76.3(8.3)	59.0 - 96.9
Body Fat(%)	16.0(5.3)	4.4 - 26.8
Lean Body Mass(kg)	64.1(6.6)	48.6 - 80.6
$\dot{V}O_2max(ml \cdot kg^{-1} \cdot min^{-1})$	58.6(5.7)	48.3 - 67.2
HRmax(bpm)	197.0(6.0)	182.0 - 210.0

TABLE 2. LEG STRENGTH AND ENDURANCE MEASURES IN NEWTON-METERS

VARIABLE	MEANS (SD)	RANGE
Quadriceps		
Extension 30°/sec	234.8(30.5)	167.2 - 298.3
Extension 180°/sec	138.0(27.9)	87.6 - 191.8
Extension PT*	129.5(28.2)	80.8 - 191.2
Extension MT**	85.0(18.7)	51.2 - 139.6
Extension % Decrement	61.6(7.4)	48.3 - 78.1
Hamstrings		
Flexion 30°/sec	99.7(17.6)	63.3 - 126.6
Flexion 180°/sec	70.9(14.9)	47.5 - 93.1
Flexion PT*	64.5(14.2)	40.6 - 87.1
Flexion MT**	50.1(9.8)	33.8 - 72.4
Flexion % Decrement	35.6(13.5)	2.7 - 57.0

* Mean highest peak torque value

** Mean peak torque (50 contractions)

Table 3 presents mean oxygen consumption ($\dot{V}O_2$) and heart rate data for all subjects at three different treadmill walking velocities while carrying a 46Kg total load. The $\dot{V}O_2$ is expressed in three ways: liters/minute, milliliters per Kg body weight, and milliliters per Kg total weight. The HR - $\dot{V}O_2$ relationship was measured at three separate intervals during the course of fifteen minute walk that progressed through three march velocities. Figure 1 illustrates the relationship observed between treadmill march velocity and oxygen consumption. Table 4 presents the average time (minutes), mean HR, and percent maximal HR as calculated by the Karvonen method (12), for the four load bearing trials.

Figures 2 through 5 illustrate heart rates from squad 1 during the 4 distance trials expressed as a percentage of maximal HR range. The values from squad 1 were representative of those observed for the 28 subjects from this study. Mean % maximal HR is represented by the dashed line at the center of the graph. The range of heart rate intensities observed from these figures indicate that a wide range of effort was exerted among subjects during the course of the four march distances.

Figure 6 presents mean % HRmax and mean march velocities plotted over distance for the four load bearing trials. It can be seen from this figure that march velocity and % HRmax intensity are closely related and decrease similarly with increasing march distance.

Table 5 presents Pearson correlation coefficients for those measured components having the highest association to performance time for all subjects from the four load bearing trials. There were no significant single physiological correlates to march performance, for the total group, at the shorter 2 and 4 km distances. However, at the 8 and 12 km distances both quadricep and hamstring strength and endurance measures exhibited significant correlations to load bearing performance.

TABLE 3. HR-$\dot{V}O_2$ RELATIONSHIP DURING TREADMILL WALKING (MEAN(SD)).

		OXYGEN CONSUMPTION		
VELOCITY(km/hr)	HR(bpm)	$L \cdot min^{-1}$	$ml \cdot KgBW^{-1} \cdot min^{-1}$	$ml \cdot Kg\ tot\ wt^{-1} \cdot min^{-1}$
3.6	119(20)	1.28(.19)	16.7(1.8)	10.7(2.1)
4.8	136(19)	1.59(.17)	20.8(2.3)	13.3(2.5)
6.0	162(17)	2.32(.25)	30.3(3.1)	19.4(3.2)

TABLE 4. MARCH TIME, HR, and % HRmax (MEAN ± SD)

DISTANCE(km)	TIME(SD)	N	HR(SD)	% HRmax(SD)*
2	16.7(2.8)	27	165(16)	74(13)
4	36.3(5.0)	27	161(19)	71(15)
8	76.2(7.6)	20	158(10)	69(9)
12	127.4(12.3)	24	150(9)	63(7)

*Karvonen method

Figure 1: Treadmill March Velocity and Oxygen Consumption (All Subjects)

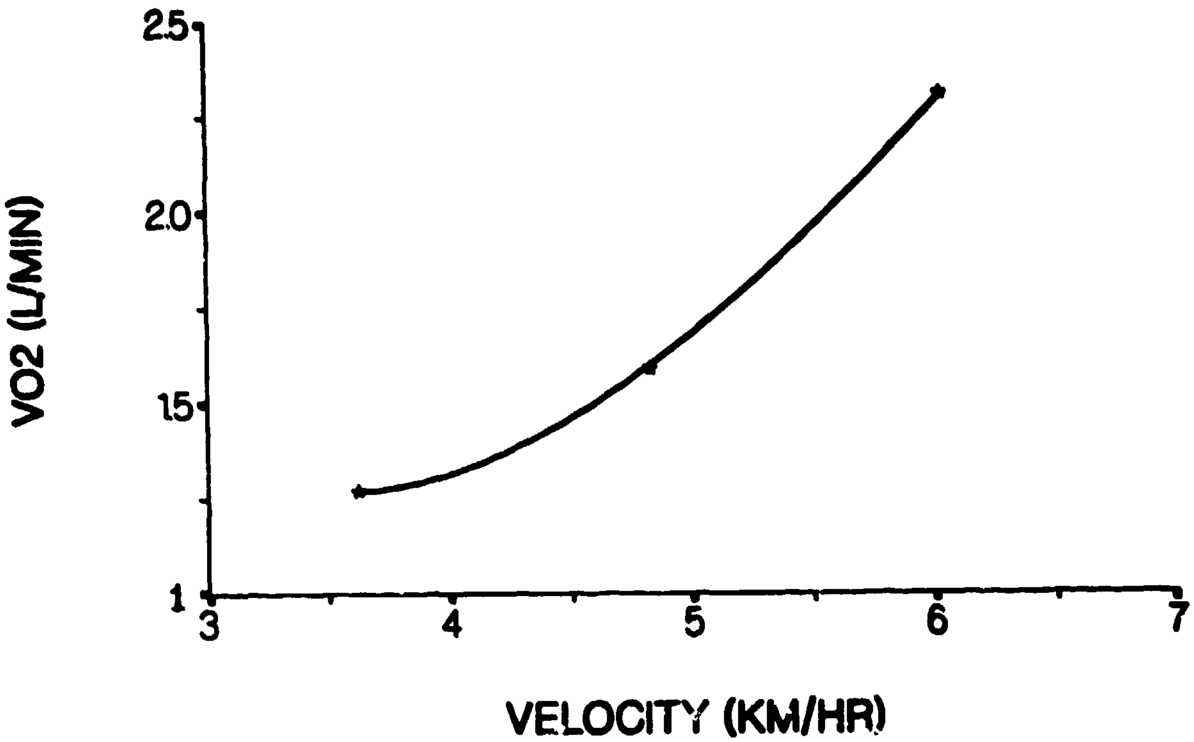
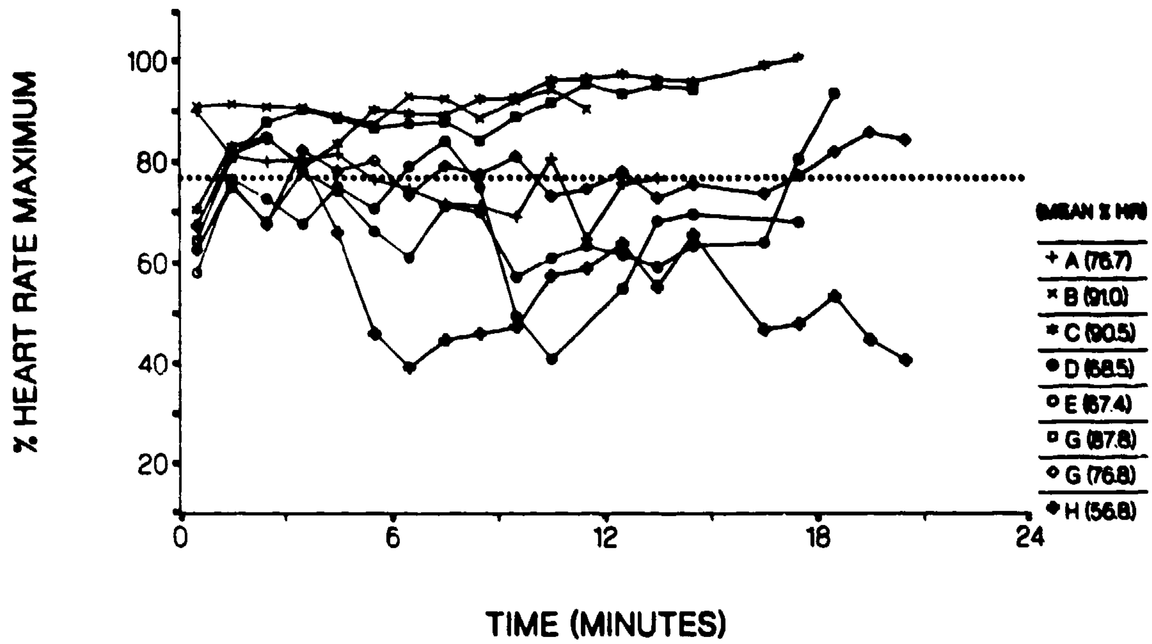


Figure 2: 2 km March Time and % HRmax (Squad 1)



<u>Figure 3:</u> 4 km March Time and % HRmax (Squad 1)

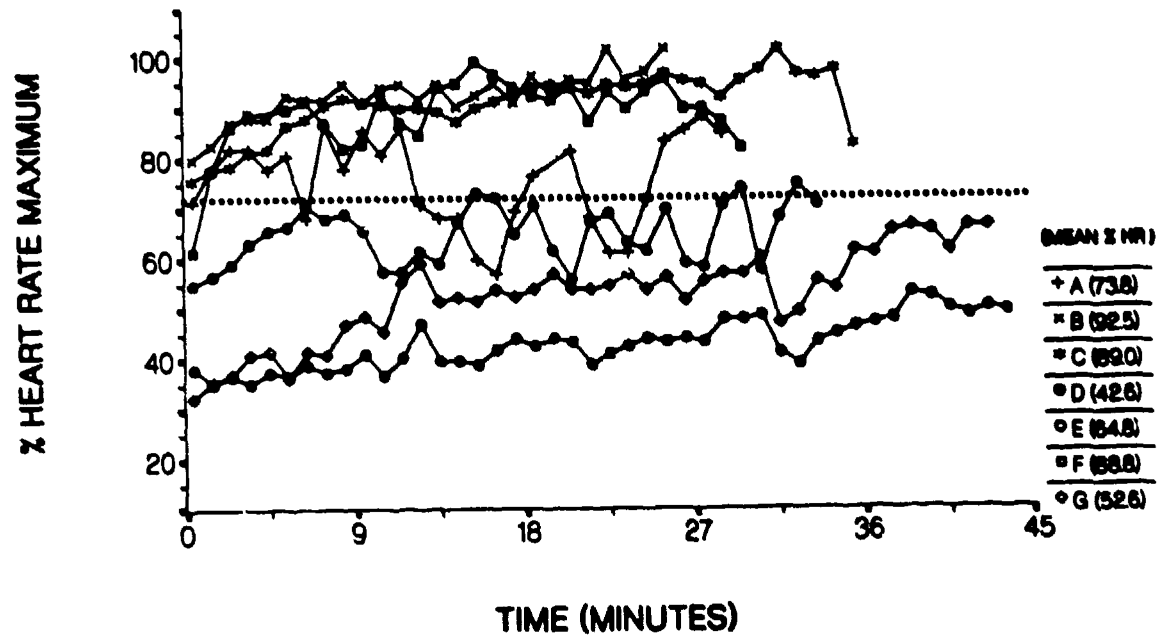


Figure 4: 8 km March Time and % HRmax (Squad 1)

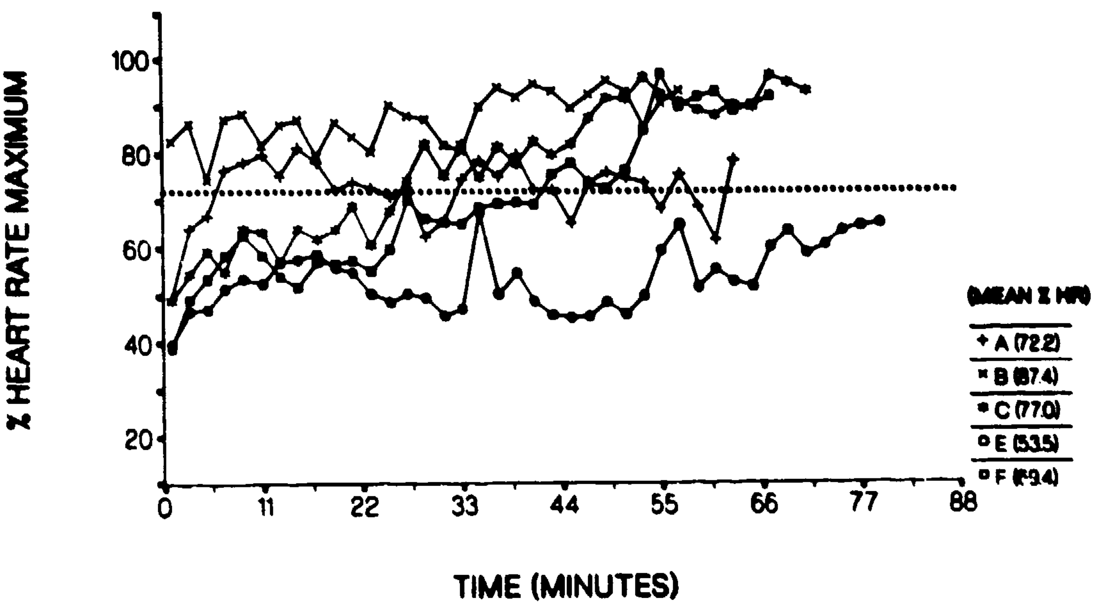


Figure 5: 12 km March Time and % HRmax (Squad 1)

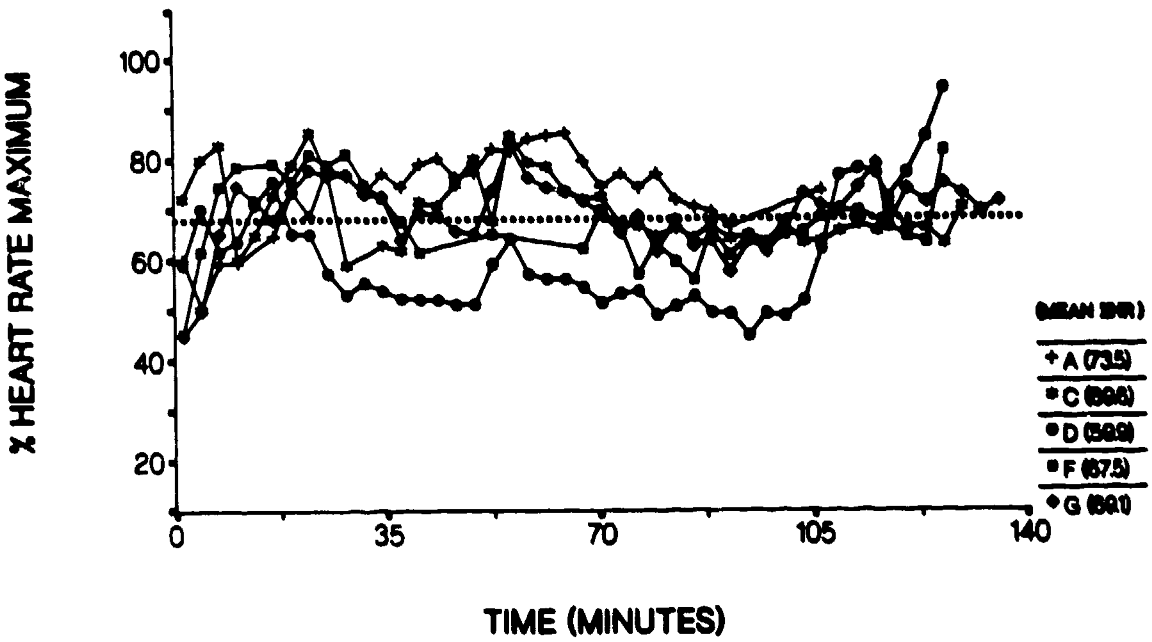


Figure 6: March Velocity and % HRmax Over Distance

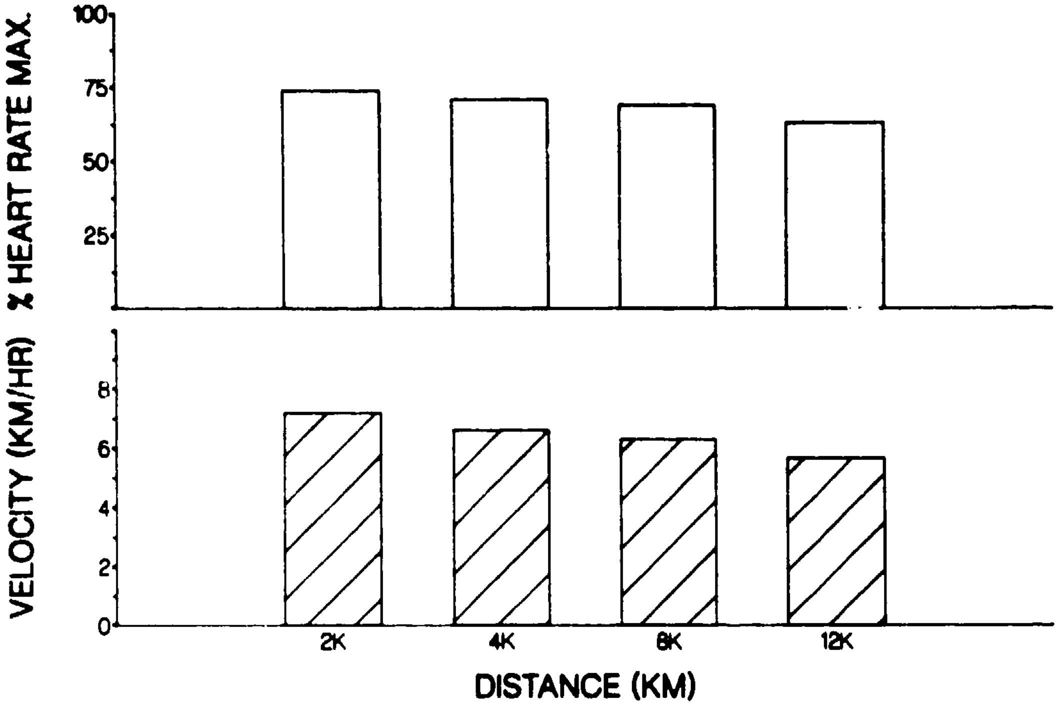


TABLE 5. **CORRELATION OF PHYSIOLOGICAL COMPONENTS TO LOAD BEARING PERFORMANCE (All Subjects)**

Variable	2KM	4KM	8KM	12KM
HT	-.130	-.190	-.330	-.030
WT	-.050	-.140	-.030	-.090
%Fat	.190	.380	.488*	.210
LBM	-.210	-.310	-.350	-.250
$\dot{V}O_2max(L)$	-.260	-.130	-.100	-.340
Q-EXT 30°	-.080	-.150	-.462	-.447
Q-EXT 180°	-.140	-.240	-.402	-.340
Q-EXT PT	-.120	-.250	-.508*	-.490*
Q-EXT MT	-.050	-.070	-.641*	-.403
H-FLX 30°	-.040	-.320	-.533	-.591*
H-FLX 180°	-.140	-.180	-.537*	-.332
H-FLX PT	-.080	-.270	-.608*	-.480*
H-FLX MT	-.180	-.220	-.504*	-.552*

Q = Quadriceps. H = Hamstrings. * = Significant ($p<.05$)

EXT = extension FLX = flexion

Since motivation to give a maximal effort during the march may play a key role in identifying the physiological determinants of performance, we decided to re-examine exercise intensities or the relative degree of effort as estimated by % HR MAX during the marches. Table 6 represents data from the upper half of the total group in terms of % HR max from the four load bearing trials. Comparing Table 6 with Table 5, it can be seen that the relationship of leg strength and endurance to load bearing performance was generally stronger at the 8 and 12 Km distance for subjects above the group mean % HR max. Hamstring flexion was also significant at the 4 km distance in this group. Subjects below the group mean % HR max level had no consistent physiological correlates to load bearing performance at any distance.

TABLE 6. CORRELATION OF PHYSIOLOGICAL COMPONENTS TO LOAD BEARING PERFORMANCE FOR SUBJECTS ABOVE MEAN % HR MAX

VARIABLE	2 KM	4 KM	8 KM	12 KM
HT	-.318	-.088	-.384	-.164
WT	-.580*	-.107	-.162	-.353
% FAT	.002	.382	.484	.291
LBM	-.538*	-.391	-.451	-.546
$\dot{V}O_2max$(L)	-.390	-.234	.063	-.528*
Q-EXT 30°	-.334	-.374	-.536*	-.528*
Q-EXT 180°	-.463	-.389	-.366	-.475
Q-EXT PT	-.512*	-.394	-.603*	-.637*
Q-EXT MT	-.289	-.439*	-.752*	-.485
H-FLX 30°	-.191	-.453*	-.799*	-.742*
H-FLX 180°	-.202	-.443*	-.750*	-.265
H-FLX PT	-.085	-.494*	-.763*	-.424
H-FLX MT	-.028	-.591*	-.457	-.422

Q = Quadriceps, H = Hamstrings, * = Significant ($p<.05$)

EXT - Extension, FLX - Flexion

DISCUSSION

This study was designed to further our knowledge of the physiological and anatomical factors that are important in determining a soldier's load carriage performance capacity. This information is needed to effectively design and evaluate potential training programs for enhancing load carriage performance of the soldier. This study found that, of the physiological and anatomical variables measured, hamstring and quadriceps muscle strength and endurance were the only variables consistently related to load carriage performance. This relationship, however, was only evident at the longer distances suggesting that other factors may be more important at the shorter distances. At 2 km in the "best effort" subjects, both total body weight and lean body mass exhibited significant correlations to performance. This may suggest that total body anaerobic power (not measured in this study) may be an important factor in high intensity load carriage at short distances. This is supported by the study of Kraemer, et al. (13) in which a combination of running and resistance training improved short distance best effort load carriage performance.

Previous studies (1,5,14,19) have mentioned the importance of not overloading infantrymen with unrealistic loads. Tactical mobility of an infantry unit is critically important to combat success, hence, an infantryman's total load should not significantly diminish his capacity for purposeful activity following load carriage. The load used in this study (46 kg/101 lbs) was purposely chosen to stress the infantrymen at a range of march distances. In fact, several of the infantrymen experienced considerable difficulty in completing the longer load bearing distances. Yet, loads borne in this study were comparable to or less than those carried by infantrymen in both the Grenada and Falkland campaigns (6,19).

The intention at the beginning of the study was to calibrate each test subject for his $\dot{V}O_2$ and heart rate response at set velocities on the treadmill and compare them to expected velocities during the field marches. However, velocities were chosen which were lower than those experienced in the actual load bearing marches. This restricted, therefore, the ability to compare march performance to treadmill calibration measures. Nevertheless, relative exercise intensities could be estimated from treadmill heart rate recordings.

Further examination of the relationship of HR intensity to load bearing performance suggests that infantrymen tended to pace or conserve themselves in direct proportion to the distance covered. This is illustrated in Figure 6 where HR intensity levels paralleled march velocity rates for the four march distances. Hence, at the longer distances, a lower sustained % HR max was seen, while at the shorter distances a higher, near maximal level was observed.

For the three longest march distances, it appeared that a soldier's ability to bear a heavy load was directly related to the strength and conditioning of his legs. The most significant physiological correlates with march performance time(s) were: hamstring strength and endurance measures and quadriceps strength and endurance measures. Since both the hamstring and quadriceps muscles are important in such activities as walking and running, and due to the high collinearity of the strength/endurance measures, no determiniation was made as to which muscle group was more important to load bearing ability. Rather, both muscle groups were considered significant determinants of load bearing capacity.

Most subjects in this study experienced similar discomforts at the completion of each load bearing trial. These included: shoulder pain from straps of the pack and vest, lower back pain from pack weight and position, and lower extremity disorders such as foot blisters, sprained ankles, and knee pain. It is critical when carrying loads of this magnitude that the pack be properly secured and not allowed to loosen and pull away from the body thus creating undue stress on the muscles of the shoulders and lower back. In this situation, the soldier would be forced to lean forward in an awkward manner in order to maintain the proper center of gravity thus adversely affecting load bearing performance and causing possible injury. It is the authors' opinion that in order to carry heavy loads, one must stabilize and distribute the load so that it is in proper alignment with the vertebral column and fits snugly upon the larger muscles of the shoulders and upper back. Future load bearing studies should include strength and endurance measures of the trunk and shoulders in order to determine the contribution of upper body components to load bearing capacity.

When one evaluates individual performance in a maximal-effort endurance event such as load bearing, it becomes difficult to relate specific physiological parameters to overall performance results (11). Such intangibles as motivation, competitiveness, and the mental toughness to drive the body forward despite the onset of pain become critical variables to load bearing performance. A soldier's inner drive or will to succeed in completing a task such as load bearing may be just as important as his $\dot{V}O_2max$, muscle strength, or muscle endurance. It is the author's opinion that a strongly motivated soldier of average size, strength, and conditioning would outperform a poorly motivated soldier of superior size, strength and aerobic capacity. Hence, fitness to perform a task such as load bearing requires the proper combination of a number of factors - anatomical, physiological, and motivational in order to achieve successful performance.

In conclusion, significant correlations were found between strength and endurance of the hamstrings/quadriceps muscle groups and heavy load bearing performance at the three longest march distances (4, 8, and 12 km). The ability to bear heavy loads for long distances requires a strong will and a physical capacity to endure significant pain and discomfort.

Finally, an important consideration in heavy load bearing is the soldier's physical capacity at the completion of the load march. The fatigue caused by heavy load bearing during the approach march must not be so great as to prevent the soldier from completing his mission upon arrival at the objective. It is, therefore, critical to choose a load whose limit is practical for Infantrymen to carry into combat.

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